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STUDY OF SEISMIC PROPAGATION PATHS AND REGIONAL TRAVELTIMES IN THE CALIFORNIA-NEVADA REGION

ARPA Order No. 193-61
Project Code No. 8100

Semiannual progress report for the period December 30, 1960, to May 31, 1961

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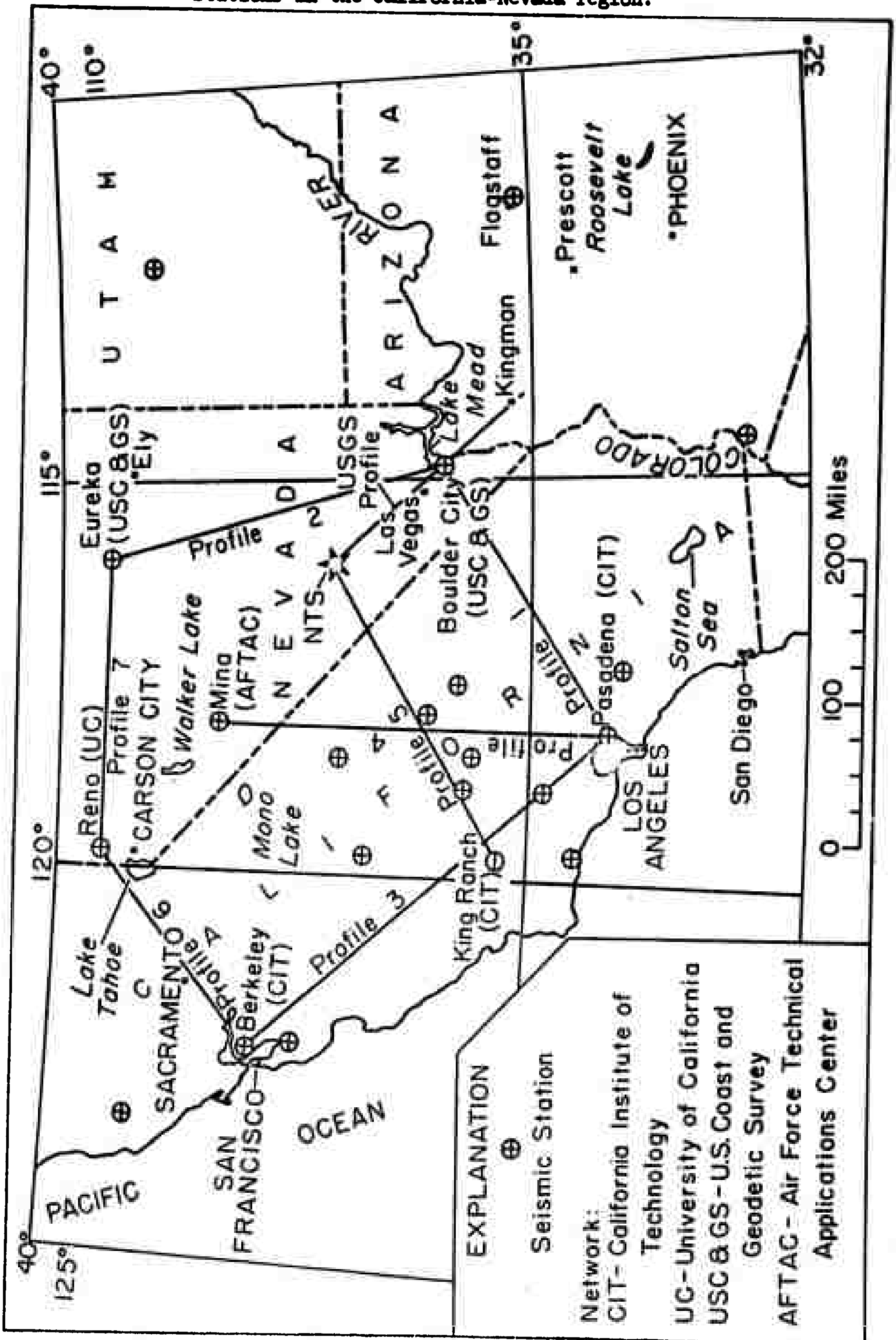
Introduction -- This semiannual report covers progress of the U. S. Geological Survey's Crustal Studies group at Denver, Colorado, from the date of ARPA Order No. 193-61, December 30, 1960, to May 31, 1961. The Crustal Studies group was established on June 17, 1960, following authorization of AFTAC Project VT/065 in April 1960. The Crustal Studies group functions as a branch-level organizational unit within the Geologic Processes Subdivision of the Geological Survey's Geologic Division. L. C. Pakiser, as Chief of Crustal Studies, is under the general supervision of J. R. Balsley, Assistant Chief Geologist for Geologic Processes. On May 31, 13 full-time professional employees, 7 full-time technicians, and 3 full-time administrative employees were assigned to Crustal Studies.

During the report period, emphasis was placed on developing new seismic equipment for long-range seismic-refraction profiling, shot-point to recorder communications, and timing, and establishing and training an organization to carry out seismic field work for crustal studies. In addition, gravity studies were made in a number of regions, and certain theoretical studies were performed.

In general, the aspects of this work discussed under "Instrumentation" in the following sections were done under the direct supervision of R. E. Warrick; work discussed under "Seismic Field Operations" was supervised by W. H. Jackson; work discussed under "Gravity Studies" was supervised by D. J. Stuart; and work discussed under "Theoretical Studies" was supervised by S. W. Stewart.

At the end of the report period, ability to carry out long-range seismic-refraction profiling had been essentially achieved, and detailed plans had been made for shooting 7 lines (Fig. 1) in the California-Nevada region. Preliminary evaluation of field problems in the California-Nevada region was in progress at the end of the report period. Shooting and recording in California and Nevada is scheduled to begin on September 4, 1961. In California and Nevada, two shot-point and 5 recording crews will be provided by a commercial geophysical contractor; overall management and 5 recording crews will be provided by the Geological Survey. Observers for the recording crews to be provided by the contractor will be thoroughly trained by the Geological Survey before field work in California and Nevada begins.

Figure 1.--Locations of proposed seismic-refraction profiles and seismic stations in the California-Nevada region.



__Instrumentation__ -- The first unit of the Geological Survey's new seismic-refraction system (which was built to our specifications by Dresser Electronics, SIE Division) was tested from February 17 to 24 in the Houston, Texas, area (Warrick and Hoover, in press). The new system features a combination of a reel-to-reel magnetic-tape recorder and a photographic oscillograph for recording seismic waves. The eight seismic-amplifier outputs are displayed on the oscillograph at two levels of amplifcation separated by 15 db. Six of the amplifier outputs are recorded on the magnetic tape at two levels separated by 30 db. The dual-level recording permits recovery of seismic data of wide dynamic range. The condensed specifications for this system are:

Low internal noise: Maximum peak-to-peak noise voltage, referred to input, in the 1 to 26 cps pass band is 0.15 microvolt with a 400-ohm input termination.

Frequency response: 3 db down at 1 cps and 300 cps on magnetic tape. The oscillograph is down 3 db at 200 cps (Fig. 2).

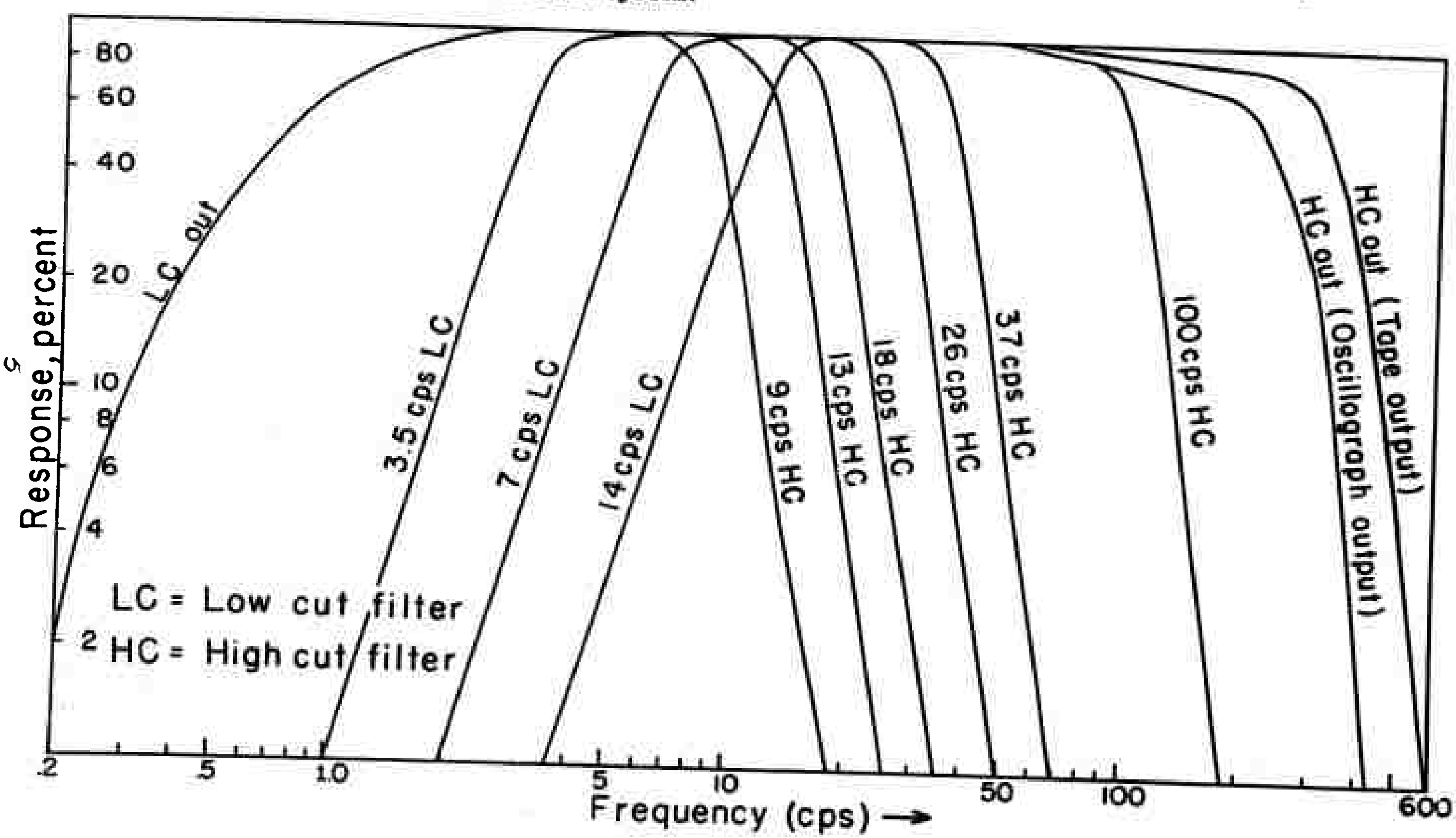
Filters: High cut with 3-db-down frequencies of 9, 13, 18, 26, 37, and 100 cps, and out, with a choice of attenuation slopes of 18 or 36 db per octave;

Low cut with 3-db-down frequencies of out, 3-1/2, 7, and 14 cps, and a slope of 18 db per octave (Fig. 2).

Dynamic range: Greater than 60 db.

Input attenuator: 84-db range in 6 db steps.

Figure 2. -- Composite, normalized frequency-response curves for the U. S. Geological Survey's new seismic-refraction system.



Playback of the data stored on magnetic tape is accomplished through the filters and output stages of the amplifiers, and conventional seismograms are recorded on the oscillograph.

The first unit met all specifications and demonstrated the value of the magnetic-tape recorder with playback. The second unit was nearly complete at the end of this report period and was undergoing performance tests prior to its acceptance in the contractor's plant at Houston. The second and following units will have physical layout superior to that of the first and more fieldworthy magnetic-tape systems. The magnetic-tape system of the first unit developed many troubles in the field, mainly because it was not well suited for highly mobile operations.

Samples of three different seismometers having natural resonance frequencies in the 1- to 2-cps range were tested in an effort to determine the type best suited for use in our refraction program. The tests included checks for spurious-mode responses, uniformity of output over a range of driving frequencies, damping checks, and evaluation of the relative difficulty of handling in the field.

The communications system, developed in our own laboratory, for seismic field operations consists of a combination of high- and low-frequency equipment. Three high-frequency allocations in the 3- to 8-megacycle range (3237, 5287.5, and 7880 kc) are used for general-purpose radiotelephone and shot-instant signaling among all mobile recording units and the shot points when propagation conditions are good. The low-frequency (180 kc) will be used to transmit shot-time instants. The low-frequency transmitters will be at the shot points, and each recording unit will have a low-frequency receiver. Tests of the low-frequency equipment showed it to be reliable out to 350 miles (day and night) and at times when the high-frequency signals were variable and sometimes unreliable. A shot-point communications trailer is being set up to include both high- and low-frequency transmitters and receivers, precise timing, and recording equipment.

Timing at the shot points and recording units is accomplished by a combination of WWV receivers and precise chronometers.

Seismic field operations -- Field measurements using the prototype seismic-refraction system were started with acceptance tests near Houston, Texas, from February 20 through 24, 1961 (Jackson, Pakiser, and Roller, in press), and were resumed on April 4 when a field training course was started for Geological Survey personnel in eastern Colorado.

During both the acceptance tests and the eastern Colorado work, the adaptability of this equipment to recording long-offset shots has been demonstrated. For example, a recording was made of an explosion of a 100-pound charge at a distance of about 40 kilometers, using a 2.5-kilometer spread of six 2-cycle seismometers (Fig. 3). The natural seismic-noise level at the recording site was extremely high -- equivalent to a signal input of between 10 and 15 microvolts rms. Only secondary arrivals could be identified on the unfiltered record (top seismogram, Fig. 3) which was made with a band pass of from 1 to 37 cps.

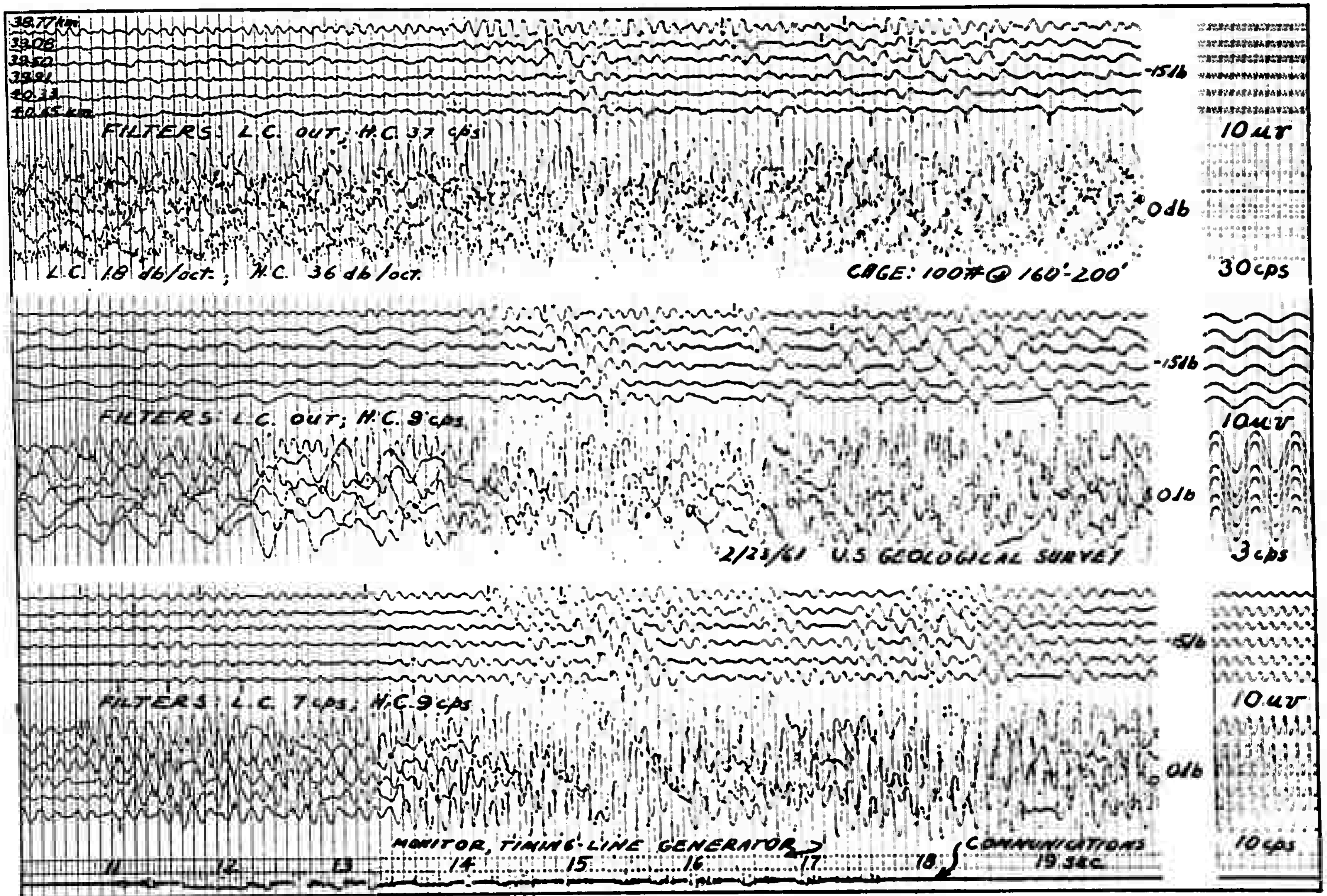


Figure 3. -- Seismograms obtained by playing back magnetic tape obtained from a shot near Houston, Texas, using different filter settings on the new seismic-refraction system.

On playback, only a slight improvement was obtained by decreasing the high-cut filter to 9 cps (center seismogram) because of the strong low-frequency background noise. However, by narrowing the band pass from 7 to 9 cps on playback (bottom seismogram), the first arrivals were clearly recovered.

The field training program was started April 4 with measurements near Lamar, Colorado, extending northward toward Sterling, Colorado. A cooperative arrangement was made with the Colorado Game and Fish Department to shoot in Nee Granda Reservoir near Lamar and in Prewitt Reservoir near Sterling.

From April 4 to May 30, 34 shots of 400 pounds and less were recorded at distances from the shot point up to 94 kilometers. Strong first arrivals of velocity approximately 6 km per sec and frequency approximately 11 cps were observed.

A comparison was made between water and drill-hole shooting to determine if there was an appreciable difference in energy transfer between the two. A slight improvement was observed with a water shot of 200 pounds compared with the same amount fired in a drill hole, recorded at the same distance.

Preliminary studies were made to determine the extent of fish kill in bodies of fresh water. This work, done in cooperation with the Colorado Game and Fish Department, was based on a single 200-pound shot placed on the floor of Nee Granda Reservoir at a depth of 30 feet. Within approximately 200 feet from the detonation point all fish (carp) were killed; from 200 to about 700 feet the fish were stunned and some may have died. Beyond 1,000 feet there appeared to be no adverse affects to the fish population.

Arrangements were made for the Quality of Water Branch of the Geological Survey to analyze water samples before and after explosions in the reservoirs to determine the extent of contamination caused by the ammonium-nitrate explosive used in this work. During the first period of training, 7 men were given field experience in the operation of the new seismic equipment.

Gravity studies -- Gravity studies were continued from earlier work in the Southern Rocky Mountains, Colorado, Sierra Valley, California, Snake River Plain, Idaho, and Yellowstone Plateau, Idaho, Montana, and Wyoming.

In the Colorado Rocky Mountains, new field work completed a profile from within the Denver Basin to the Colorado Plateau. This detailed profile shows that the Southern Rocky Mountains are isostatically compensated on a regional scale, and it suggests that local compensation does not prevail in this region (Stuart and Wahl, in press). A correlation between Bouguer-anomaly values and Precambrian basement rock configuration was observed.

Interpretative work on Sierra Valley gravity data suggests that the valley is bounded by steeply-dipping faults, and in its deepest part is filled with at least 2,500 to 3,000 feet of low-density deposits of Cenozoic age (Jackson, Shawe, and Pakiser, in press).

In the western Snake River Plain, the mass excess of three large gravity highs reported previously (Fig. 4) was found by application of Gauss's theorem to be about 1×10^{19} g. This is equivalent to a volume of 8,000 mi^3 of material 0.3 g per cm^3 more dense than the surrounding material. The anomaly-causing bodies extend from near sea level to at least 20,000 feet and possibly as much as 60,000 feet below sea level. A proposed geologic explanation for the anomalies involves a graben filled with basalt flows extending to about 10,000 feet or 3 km below sea level and a series of basalt-filled, en-echelon fissures extending from the bottom of the graben to about 60,000 feet or 18 km below sea level (Hill, Baldwin, and Pakiser, in press; Hill and Jacobson, 1961).

The previously-reported Yellowstone Plateau gravity low (Fig. 5) has been interpreted as the expression of a large volume of near-surface silicic rocks of low average density. The volume of rock represented by the low was found by Gauss's theorem to be about half that of the western Snake River Plain. This is equivalent to a disc of rocks 0.3 g per cm^3 less than the rocks that surround them about 40 miles in diameter and 20,000 feet or 6 km thick. These rocks take the form of a thick lens of rhyolite, a magma chamber, a silicic batholith, or some combination of these (Pakiser and Baldwin, in press). The low west of the Madison Range may express a graben filled with low-density Cenozoic deposits.

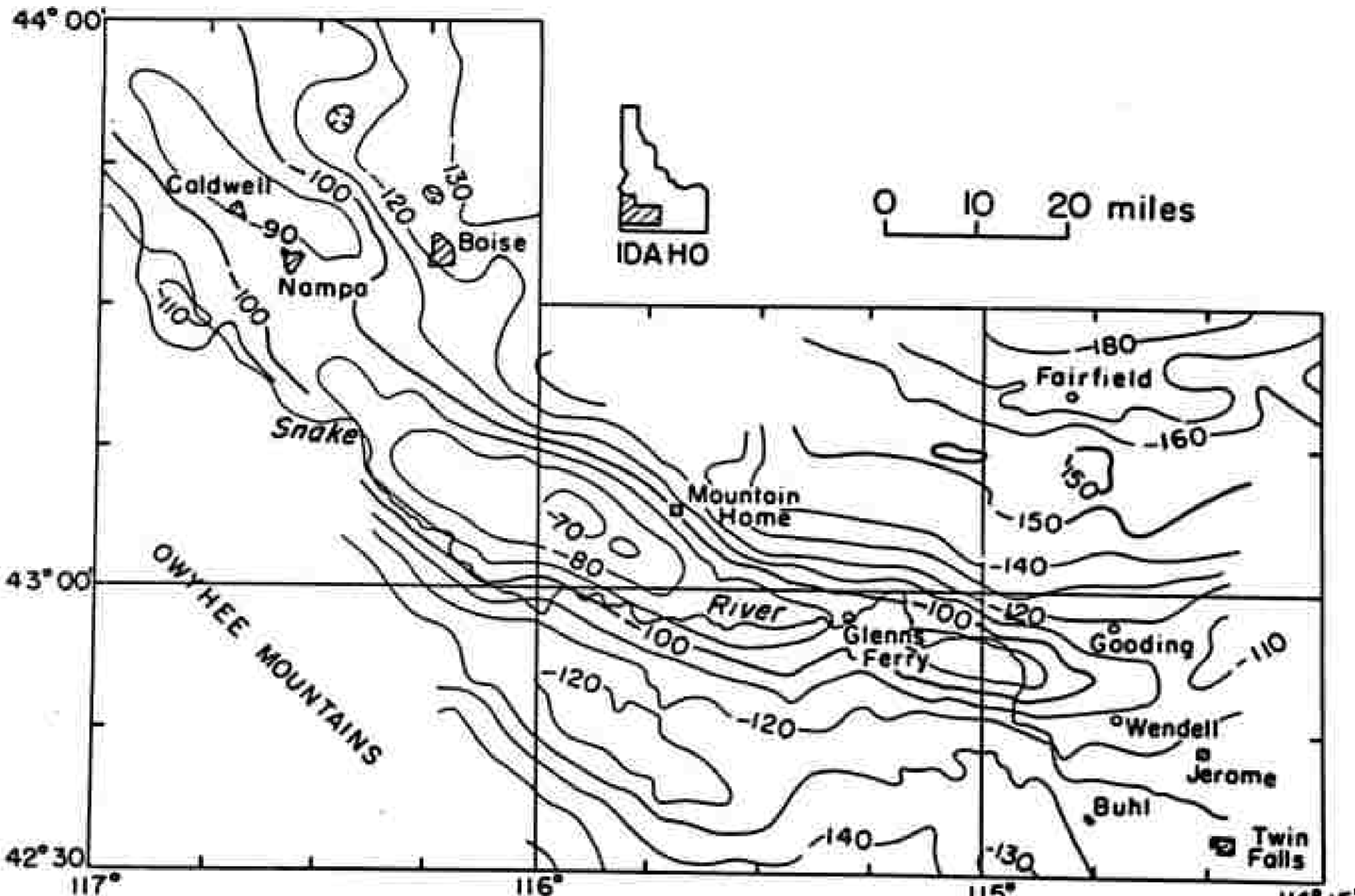


Figure 4. -- Simple-Bouguer gravity map of part of the Snake River Plain, Idaho.

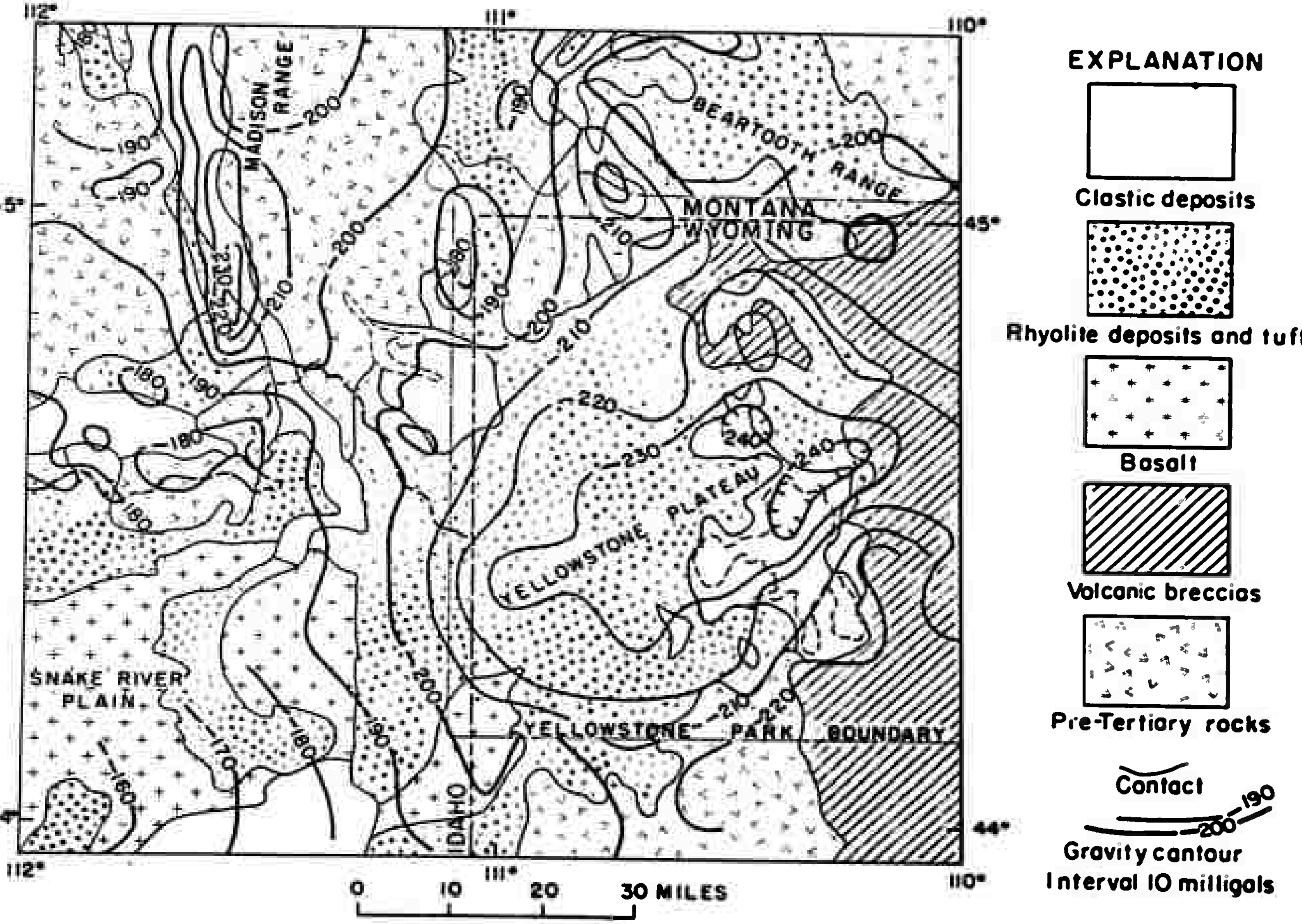


Figure 5. -- Combined gravity and geologic map of the Yellowstone region, Idaho, Montana, and Wyoming.

Theoretical studies -- During this report period emphasis was placed on detailed study of the digital-computer program for calculating the frequency content of seismic waves, rather than on continued calculation of the spectra for various seismic events. As a result, the characteristics of the frequency spectrum calculated by this program are now more clearly understood. For example, because only finite lengths of a seismogram trace are involved in the calculation, and because the seismogram trace is presented to the computer in a digital form, the frequency spectra so computed are necessarily composed of discrete spectral components, and the frequency spectrum necessarily has a limit placed on the highest frequency component that may be uniquely determined by the computer program. Further, it is now possible to interpret the amplitude components of the calculated frequency spectrum in units of actual trace amplitude, rather than arbitrary units as was done previously. If the frequency response of the seismic recording system is known, then it is possible to resolve the seismogram into frequency components related to actual ground amplitude.

To test the ability of the computer program to resolve a seismogram into discrete frequency components, part of a seismogram was digitized and analyzed for frequency content, and then reconstructed at 21 points from the calculated amplitude, phase, and frequency data. The amplitudes for the reconstructed seismogram had a root-mean-square deviation from the observed amplitudes of about 0.8 millimeters; the actual seismogram amplitudes ranged up to ±32 millimeters from the zero-amplitude line.

During this report period studies of surface-wave dispersion for Love and Rayleigh waves were started. The initial method of approach was to use an existing digital-computer program to calculate dispersion curves for reasonable models of crust-mantle systems. Emphasis has been placed on determining the ability of surface waves to distinguish among various crustal models, holding the properties of the mantle constant. Table I summarizes the properties of the two crustal models studied in the most detail. Model A is characterized by a layered crust in which successively deeper crustal layers have successively higher compressional and shear velocities; Model B has a "low-velocity" layer, for both compressional and shear waves, within the crust. (Crust is used here to include all layers, from the surface down, lying above the layer having compressional wave velocity of about 8.1 km per sec.)

Models A and B are modifications of models 5CM and 5EE reported by Press (1960) in his study of crustal structure in the California-Nevada region. The parameters marked by an asterisk in Table I are those determined by Press (1960) from seismic-refraction and/or earthquake data, and are regarded as fixed, at least within very narrow limits. In both models the presence of the mantle low-velocity zone is taken into account, and both models are compatible with Press's traveltime and Rayleigh-wave phase-velocity data in the region.

Table I.-- Crust-mantle models used in surface-wave dispersion calculations

Model A

Layer No.	Layer thickness, km	Compressional velocity, km/per/sec	Shear velocity, km/per/sec	Density, g per cm^3	Poisson's ratio
1	1.045	3.0347	1.7199	2.20	0.2634
2	23.0*	6.0693*	3.49*	2.78	0.2530
3	25.1	7.6870*	4.0460	3.14	0.3084
4	15.7	8.0929*	4.6530*	3.37	0.2531
5	20.9	7.9606	4.5620	3.42	0.2555
6	infinite	7.8893	4.4910	3.43	0.2603

Model B

Layer No.	Layer thickness, km	Compressional velocity, km/per/sec	Shear velocity, km/per/sec	Density, g per cm^3	Poisson's ratio
1	1.000	3.0347	1.7199	2.20	0.2634
2	23.0*	6.0701*	3.49*	2.78	0.2531
3	6.0	7.6875*	4.40	3.23	0.2564
4	12.0	6.9998	3.6843	3.25	0.3084
5	15.0	8.0929*	4.6530*	3.37	0.2531
6	20.0	7.9607	4.5620	3.42	0.2555
7	infinite	7.8904	4.4910	3.43	0.2604

These models are significant in that their computed Rayleigh-wave dispersion curves, both for phase velocity and group velocity, seldom differ by more than ±0.01 km per sec for any given period over the period range 1-150 seconds. This difference is approximately the error to be expected in observed dispersion data of good quality. There is no reason to expect greatly different results for Love-wave dispersion curves. This suggests that an unique solution of the velocity structure of the earth's crust requires highly-accurate experimental data from many sources.

Preliminary study has been made of the Airy phase of Rayleigh waves recorded at short distances from explosions in eastern Colorado.

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